Interoperability for Smart Appliances in the IoT World

Laura Daniele[1(✉)], Monika Solanki[2], Frank den Hartog[1], and Jasper Roes[1]

[1] TNO - Netherlands Organization for Applied Scientific Research, The Hague, The Netherlands
{Laura.Daniele, Frank.denHartog, Jasper.Roes}@tno.nl
[2] Department of Computer Science, University of Oxford, Oxford, UK
Monika.Solanki@cs.ox.ac.uk

Abstract. Household appliances are set to become highly intelligent, smart and networked devices in the near future. Systematically deployed on the Internet of Things (IoT), they would be able to form complete energy consuming, producing, and managing ecosystems. Smart systems are technically very heterogeneous, and standardized interfaces on a sensor and device level are therefore needed. However, standardization in IoT has largely focused at the technical communication level, leading to a large number of different solutions based on various standards and protocols, with limited attention to the common semantics contained in the message data structures exchanged at the technical level. The Smart Appliance REFerence ontology (SAREF) is a shared model of consensus developed in close interaction with the industry and with the support of the European Commission. It is published as a technical specification by ETSI and provides an important contribution to achieve semantic interoperability for smart appliances. This paper builds on the success achieved in standardizing SAREF and presents SAREF4EE, an extension of SAREF created in collaboration with the EEBus and Energy@Home industry associations to interconnect their (different) data models. By using SAREF4EE, smart appliances from different manufacturers that support the EEBus or Energy@Home standards can easily communicate with each other using any energy management system at home or in the cloud.

Keywords: Ontology · Standardization · Semantic interoperability · Internet of things · Smart appliances

Resource type: Ontology
Permanent URL: https://w3id.org/saref and https://w3id.org/saref4ee

1 Introduction

In the past years, standards organizations, alliances and consortia in the Internet of Things (IoT) have focused on enabling interoperability at the technical communication level, creating a large number of different solutions based on various data models, specifications and protocols that are characterized by non-interoperable concepts [1].

P. Groth et al. (Eds.): ISWC 2016, Part II, LNCS 9982, pp. 21–29, 2016.
DOI: 10.1007/978-3-319-46547-0_3

To overcome this fragmentation, it became necessary to move towards a common, harmonized solution that could enable interoperability at the semantic level, i.e., to understand the concepts contained in the message data structures that are exchanged at the underlying technical level, regardless of the specifics of the underlying communication protocols [2]. The need to address the semantics of standards has been acknowledged as an important action in the upcoming IoT standardization activities towards an interoperable and scalable solution across a global IoT ecosystem [3].

In 2015, we created SAREF (https://w3id.org/saref), a reference ontology for smart appliances that focuses on the smart home environment, and provides an important contribution to enable semantic interoperability in the IoT [4]. As explained in our earlier work [5–7], SAREF was originally created for the energy management domain, and was developed in close interaction with the industry with the support of the European Commission (EC). SAREF has been subsequently adopted by ETSI as a Technical Specification [8]. As confirmed in [3], SAREF is a first ontology standard in the Internet of Things (IoT) ecosystem, and sets a template and a base for the development of similar standards for the other verticals to unlock the full potential of IoT. Standards organizations and alliances, such as CENELEC and the Alliance for Internet of Things Innovation (AIOTI), have acknowledged and adopted SAREF in their standardization activities [2, 9].

This paper presents SAREF4EE (https://w3id.org/saref4ee), an extension of SAREF that we created in collaboration with EEBus (http://www.eebus.org/en) and Energy@Home (http://www.energy-home.it), the major Germany- and Italy-based industry associations, to enable the interconnection of their (different) data models. EEBus is an important initiative in the area of the Internet of Things, which has its roots in the sector of smart and renewable energy, and involves partners such as BSH Bosch/Siemens, Miele, Intel and Deutsche Telekom. EEBus developed a standardized and consensus-oriented smart grid and smart home networking concept. The EEBus data model is described in [10]. The Energy@Home association, abbreviated in the rest of the paper as E@H, includes members such as Electrolux, Enel, Indesit, Whirlpool and Telecom Italia. E@H aims at developing and promoting technologies and services for energy efficiency in smart homes, based upon the interaction between user devices and the energy infrastructure. The E@H data model is described in [11]. By using SAREF4EE, smart appliances from manufacturers that support the EEBus or E@H data models will easily communicate with each other using any energy management system at home or in the cloud.

SAREF4EE was created in a 5 months project in collaboration with the EEBus and E@H stakeholders. The result is an OWL-DL ontology that extends SAREF with 115 classes, 31 object properties and 51 data type properties. SAREF4EE is a step forward towards the missing interoperability in the fragmented market of proprietary solutions developed by different consortia in the smart home domain. Towards this aim, SAREF4EE should be used to annotate (or generate) a neutral (protocol-independent) set of messages to be directly adopted by the various manufactures, or mapped to their domain specific solutions of choice, such as ZigBee, Z-Wave, KNX, OCF, AllJoin and so forth. We envision that in the immediate future we will able to demonstrate how appliances that belong to different manufactures from the EEBus and E@H associations can practically communicate with the CEM in the home using a shared semantic

standard (SAREF4EE) that abstracts from the specifics of the underlying communication protocols. This paper is structured as follows. The next section presents some background information about SAREF from which SAREF4EE was derived. We then describe the main classes and properties of SAREF4EE, followed by an evaluation according to the desired criteria, and our conclusions.

2 Background

SAREF is a reference ontology that describes the core concepts for the stakeholders in the smart appliances domain and provides a mechanism to map different existing solutions (i.e., data models, protocols, standards) to one another. SAREF is intended to be used as basis for the creation of more specialized ontologies, such as SAREF4EE presented in this paper. The main advantage is that specialized ontologies based on a reference ontology are (semantically) interoperable by construction with other ontologies that reuse the same reference ontology.

SAREF focuses on the concept of "device", which is a tangible object designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, a device performs one or more "functions". For example, a washing machine is designed to wash, and to accomplish this task it performs, among others, a start and stop function. When connected to a network, a device offers a "service", which is a representation of a function to a network that makes the function discoverable, registerable and remotely controllable by other devices in the network. A device is also characterized by an "energy profile" and a "power profile" that can be used to optimize the energy efficiency in a home or office that are part of the building. SAREF is expressed in OWL-DL and contains 110 classes, 31 object properties and 11 datatype properties. A detailed description of the main classes and properties of SAREF can be found in our earlier work [5].

The study to create SAREF was performed in a very transparent manner to allow all stakeholders to provide input and follow the work. We took a multi-channel approach to solicit for review comments: within the span of a year we organized four workshops for stakeholders together with the EC and ETSI, in which we presented the deliverables and work done, and provided an opportunity for stakeholders to provide us with feedback. Besides this quarterly interactive heartbeat of face-to-face gatherings, we had continuous interaction with all involved parties by email, LinkedIn, project's website (https://sites.google.com/site/smartappliancesproject), and by attending additional related events such as ETSI and Home Gateway Initiative (HGI) meetings. This interactive and iterative approach was a key factor of success in the creation of SAREF and its subsequent adoption by the industrial stakeholders. Although this approach created a lot of overhead work, it also guaranteed a higher practical quality of the outcome, reflecting the wishes and intentions of the community in an optimal way, and above all creating the necessary trust into our work, increasing the likelihood of a strong acceptance of the results. In this line, TNO was asked by EEBus and E@H to create the SAREF4EE extension.

3 SAREF4EE

SAREF4EE extends SAREF with 115 classes, 31 object properties and 51 data type properties. Its purpose is to demonstrate the interoperability between EEBus and E@H devices in demand response use cases. In these use cases, customers can offer flexibility to the Smart Grid to manage their smart home devices by means of a Customer Energy Manager (CEM). The CEM is a logical function for optimizing energy consumption and/or production that can reside either in the home gateway or in the cloud. These use cases can be described as follows:

- configuration of devices that want to connect to each other in the home network, for example, to register a new dishwasher to the list of devices managed by the CEM;
- (re-)scheduling of appliances in certain modes and preferred times using power profiles to optimize energy efficiency and accommodate the customer's preferences;
- monitoring and control of the start and status of the appliances;
- reaction to special requests from the Smart Grid, for example, incentives to consume more or less depending on current energy availability, or emergency situations that require temporary reduction of the power consumption.

These use cases are associated with the user stories described in [12], which include, among others, the following examples:

- User wants to do basic settings of their devices;
- User wants to know when the washing machine has finished working;
- User wants their washing done by 5:00 pm. with least electrical power costs;
- User likes to limit own energy consumption up to a defined limit;
- User allows the CEM to reduce the energy consumption of their freezer in a defined range for a specific time, if the grid recognizes (severe) stability issues;
- Grid related emergency situations (blackout prevention).

Figure 1 shows an excerpt of SAREF4EE that represents the concepts of "power profile", "power sequence", "alternative" and "slot" that are used by a device to communicate its energy flexibility to the CEM according to the consumer's preferences and needs. We distinguish between SAREF and SAREF4EE using the prefixes `saref:` and `s4ee:`, respectively.

A `s4ee:PowerProfile` inherits the properties of the more general `saref:Profile`, extending it with additional properties that are specific for SAREF4EE. The `s4ee:PowerProfile` is used by a `s4ee:Device` to expose the power sequences that are potentially relevant for the CEM, for example, a washing machine that wants to communicate its expected energy consumption for a certain day. A `s4ee:Device` can expose at most one `s4ee:PowerProfile`, which consists of one or more alternative plans (`s4ee:Alternative` class). For example, the washing machine mentioned above can offer two alternative plans, a "cheapest" alternative in which the CEM should try to minimize the user's energy bill, and a "greenest" alternative in which the CEM should try to optimize the configuration towards the maximum availability of renewable energy.

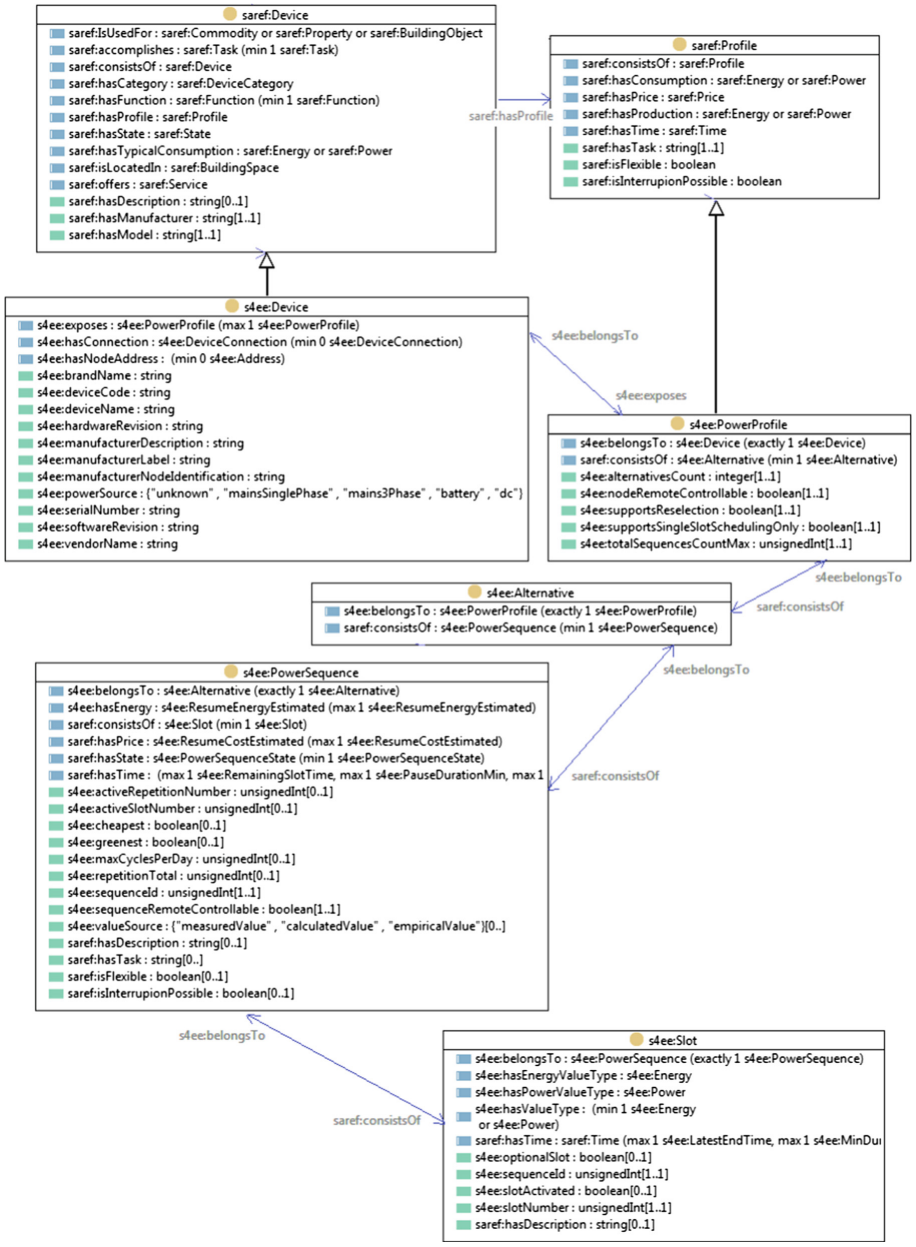

Fig. 1. Device and profile concepts in SAREF, and their extension in SAREF4EE

A `s4ee:Alternative` consists of one or more power sequences (`s4ee:PowerSequence` class). For example, in the "cheapest" alternative mentioned above, the washing machine can ask to allocate two power sequences during the night, while

for the "greenest" alternative it can ask to allocate one power sequence in the morning and one in the afternoon. Of these power sequences, one is allocated for the task of washing and cannot be stopped once it started, while the other power sequence is allocated for the task of tumble dry and has the flexibility to be paused by the CEM as long as it finishes within a specified latest end time.

A `s4ee:PowerSequence` consists of one or more slots (`s4ee:Slot` class) that represent different phases of consumption (or production) and their values. In the power sequence allocated for washing, for example, various slots can represent the consumption during the different phases of washing, such as heating the water, washing and rinsing.

4 Evaluation

An evaluation of SAREF and SAREF4EE is proposed in Table 1 in accordance to the desired criteria [13], which include ontology-specific criteria and more generic criteria that aim at demonstrating the value, potential for being reused, technical quality and availability of ontologies and other resources in the Web.

Table 1. Evaluation.

Criteria	Evaluation
Design suitability	Based on requirements specifically set by the European Commission [14] and industrial collaborators. Intermediate and final designs interactively reviewed and approved by all involved parties. High practical quality, reflecting the wishes and intentions of the smart appliances community in an optimal way
Elegance & Quality	Design based on Gruber's principles of clarity, coherence, extendibility, minimal encoding bias, and minimum ontological commitment [15]
Logical correctness	Verified using DL reasoners for satisfiability, incoherency and inconsistencies
Reuse	SAREF4EE specializes the energy-related concepts defined in SAREF, and in turn SAREF reuses the following resources:
	• based on 20 domain-specific ontologies, e.g., W3C SSN ontology (https://sites.google.com/site/smartappliancesproject/ontologies); • reuse of W3C WGS84 geo positioning vocabulary and W3C Time ontology via direct import; • reuse of Ontology of units of Measure (OM) individuals
Documentation	Ontologies self-descriptive using labels and definitions. Human readable documentation available with major ontology elements and explanatory diagrams:
	• SAREF4EE documentation - reviewed and approved by EEBus and E@H experts - elaborates on the use cases using some figures (http://ontology.tno.nl/SAREF4EE_Documentation_v0.1.pdf); • SAREF standardized by ETSI as technical specification TS 103 264 [8]

(*Continued*)

Table 1. (*Continued*)

Criteria	Evaluation
Additional value	There is widespread fragmentation in current market and technology. SAREF(4EE) is the first ontology standard in the IoT with focus on understanding the concepts contained in the message data structures that are exchanged at the technical level, regardless of the specifics of the underlying communication protocols
Societal interest	Currently in-home electrical devices from different manufacturers are connected to the Internet, but this connectivity is hardly ever used for devices communicating with each other on an application level. SAREF and SAREF4EE aim to bridge this gap
Impact	SAREF acknowledged as first ontology standard in IoT [3, 4]. SAREF4EE adopted by industrial associations EEbus and E@H to interconnect their data models. Core of ETSI Special Task Force 513 for Maintenance & Evolution of SAREF Reference Ontology
Usage	Used by a wider community beyond the resource creators, such as:
	• industrial stakeholders, e.g., from the EEBus and E@H associations, whose members include appliances manufacturers such as BSH Bosch/Siemens, Miele, Indesit, Electrolux, and Whirlpool; • oneM2M Standards for M2M and the Internet of Things for their TS-0012 oneM2M Base Ontology, built after and based on SAREF (http://www.onem2m.org/technical/onem2m-ontologies); • AIOTI Alliance for Internet of Things Innovation in their WG03 • IoT standardization activities; • CENELEC in their Smart Home standardization activities [9]; • W3C Linked Building Data community group
Ease to (re)use	Well documented using standard metadata specifications such as Dublin Core. Modular building blocks to allow recombination of different parts to accommodate different needs and points of view. For example, lists of functions, commands and states that can be combined to create complex functionality in a single device
Persistent URI	w3id URIs: https://w3id.org/saref and https://w3id.org/saref4ee
Associated citation	Various citations associated to the resource [5–7].
License	CreativeCommons 3.0 http://creativecommons.org/licenses/by/3.0/
Community registry	Registered in Linked Open Vocabularies (LOV)
Sustainability/Maintenance plan	TNO is involved in a Special Task Force funded by ETSI for the maintenance, evolution and extension of SAREF, which also includes the definition of a sustainable plan for the governance of the SAREF(4EE) network of ontologies in the future

5 Conclusions

This paper presented SAREF4EE, an extension of SAREF that was created in collaboration with the EEBus and Energy@Home industry associations to interconnect their different data models, enabling interoperability between appliances produced by different manufacturers. In this paper, we further evaluated SAREF and SAREF4EE according to some criteria that take into account the value, potential for being reused, technical quality and availability of an ontology. We conclude that SAREF and SAREF4EE satisfy these criteria. Moreover, we conclude that reference ontologies, such as SAREF, and the network of extensions possibly sprouting from them, such as SAREF4EE, play an essential role in the current standardization activities in the IoT domain, and should be used more systematically to enable better interoperability in the current fragmented market of various, often proprietary solutions and technologies. In particular, SAREF and its network of ontologies should be evolved to cover other verticals that are relevant to the IoT and the Smart Home, such as e-health, security and entertainment. To have an actual impact, however, the development of these ontologies should be driven by a real, strong industry demand, and carried out in close collaboration with the stakeholders that are willing to adopt them in specific applications, instead of as an abstract promise for interoperability that is unilaterally pushed to the market. We finally observe that the endorsement by policy makers and standardization bodies (such as the EC and ETSI) is an essential factor to promote the adoption and usage of ontologies by the industry.

Acknowledgments. The authors would like to thank Daniele Pala and Marco Signa from Energy@Home, and Andy Westermann and Josef Baumeister from EEBus for their insight and expertise that greatly assisted in the creation of SAREF4EE.

References

1. AIOTI WG03- IoT Standardisation: IoT LSP Standard Framework Concept 2.0 (2015)
2. AIOTI WG03- IoT Standardisation: IoT Semantic Interoperability 2.0 (2015)
3. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs: GROW - Rolling Plan for ICT Standardisation (2016). http://ec.europa.eu/DocsRoom/documents/14681/attachments/1/translations/en/renditions/native
4. Viola, R.: New Standard for Smart Appliances in the Smart Home. Digital Agenda for Europe, December 2015. https://ec.europa.eu/digital-agenda/en/blog/new-standard-smart-appliances-smart-home
5. Daniele, L., den Hartog, F., Roes, J.: Created in close interaction with the industry: the smart appliances reference (SAREF) ontology. In: Cuel, R., Young, R. (eds.) FOMI 2015. LNBIP, vol. 225, pp. 100–112. Springer, Heidelberg (2015)
6. Daniele, L., den Hartog, F., Roes, J.: How to keep a reference ontology relevant to the industry: a case study from the smart home. In: Tamma, V., Dragoni, M., Gonçalves, R., Lawrynowicz, A. (eds.) OWLED 2015. LNCS, vol. 9557, pp. 117–123. Springer, Heidelberg (2016). doi:10.1007/978-3-319-33245-1_12

7. den Hartog, F., Daniele, L., Roes, J.: Toward semantic interoperability of energy using and producing appliances in residential environments. In: 12th Annual IEEE Consumer Communications & Networking Conference (CCNC 2015). IEEE Press, January 2015
8. SAREF TS 103 264 V1.1.1, ETSI, November 2015. http://www.etsi.org/deliver/etsi_ts/103200_103299/103264/01.01.01_60/ts_103264v010101p.pdf
9. CENELEC TC59x WG7, prEN50631-x (2016)
10. EEBus initiative: SPINE (Smart Premises Interoperable Neutral-message Exchange) Specification V1.0.0, April 2016. https://www.eebus.org/en/specifications
11. Energy@home project: Energy@home Data Model, v2.1, October 2015. http://www.energy-home.it/Documents/Technical%20Specifications
12. IEC TR 62746-2 Systems interface between customer energy management system and the power management system - Part 2: Use cases and requirements (2015)
13. Gray, A.J.G., Sabou, M.: ISWC2016 Resources Track: Author and Reviewer Instructions. figshare, December 2015. http://dx.doi.org/10.6084/m9.figshare.2016852
14. European Commission: Invitation to tender - Study on the available semantics assets for the interoperability of Smart Appliances. Mapping into a common ontology as a M2 M application layer semantics - SMART 2013/007 (2013)
15. Gruber, T.: Toward principles for the design of ontologies used for knowledge sharing. Int. J. Hum. Comput. Stud. **43**(5–6), 907–992 (1995). Elsevier